Effects of Seeding Date on Establishment of Prairie Grasses in Minnesota

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"The chance to find a pasque flower is a right
as inalienable as free speech."

From *A Sand County Almanac*
Aldo Leopold

To my husband, Wayne,

who helped me find my way to the prairie.

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CHAPTER 1

Effects of Seeding Date on Establishment of Prairie Grasses in Minnesota

ABSTRACT

Proper seeding time is crucial for successful stand establishment of prairie grasses. This experiment investigated the effects of seeding date and species or mix on first and second-season establishment of prairie grasses. In 1996 and 1997, ten seeding dates were tested May through October, at the University of Minnesota, St. Paul. Monocultures of *Schizachyrium scoparium* (little bluestem), *Bouteloua curtipendula* (sideoats grama), *Elymus canadensis* (Canada wildrye) and *Bromus kalmii* (Kalm's brome) were evaluated, as well as a warm-season grass mix (81% warm-season grasses) and a cool-season grass mix (46% cool-season grasses).

Establishment patterns differed greatly between the two planting years. There were statistically significant effects for seeding date, mix, and seeding date × mix interaction. For 1996 plantings, by the second season establishment for May and June plantings was significantly better than for late July through October seedings. For 1997 plantings, second-season establishment for late July through September plantings was significantly higher than for May, June, and October plantings. Establishment appeared to relate to rainfall patterns.

E. canadensis had significantly higher second-season establishment than other species or mixes. Dormant seedings in late September and October were successful one of the two plantings years for *E. canadensis* and *B. kalmii*. The warm-season grasses tested, *S. scoparium* and *B. curtipendula*, had a shorter planting season, higher winter mortality, and poor establishment from dormant seedings both years. The cool-season mix had

significantly higher establishment than the warm-season mix but contained few warm-season grass seedlings.

Key words: prairie restoration, establishment, seeding date, native grasses, *Schizachyrium scoparium*, *Bouteloua curtipendula*, *Elymus canadensis*, *Bromus kalmii.*

INTRODUCTION

Sixty years after work began on Curtis Prairie, the first tallgrass prairie restoration (Howell and Jordan, 1989), ecologists and restorationists continue to seek the best establishment techniques. As late as the 1980's, methods for restoring tallgrass prairie were largely based on personal experience and word of mouth (Howell and Jordan, 1989). While many establishment experiments have been conducted on dry grasslands in the western United States, it is often inappropriate to apply these results to tallgrass prairie restorations in the northern Great Plains. One research topic that has received little attention in the tallgrass region is the effects of seeding date on early stand establishment.

Researchers in Illinois studied establishment for native and introduced grasses on mine spoils, comparing June seedings with November dormant seedings (Rodgers and Anderson, 1989). There were no significant differences in first-season seedling counts between November and June plantings. However, *Schizachyrium scoparium* (little bluestem) and *Panicum virgatum* (switch grass) produced significantly more second-season biomass when seeded in June than when dormant seeded in November (unamended plots); *Sorghastrum nutans* (Indian grass) showed no difference in biomass between spring and fall plantings.

Studies conducted in the drier climate associated with shortgrass and mixed-grass prairies establish some general trends that are likely to exist in the tallgrass prairie region as well. Researchers have found seeding date was an important factor in early stand establishment for cool-season grasses in Idaho (Douglas et al., 1960), in Saskatchewan (Kilcher, 1961; Lawrence et al., 1990), in Colorado (McGinnies, 1960; Bement et al., 1975; McGinnies, 1973), in British Columbia (McLean and Wikeem, 1983), and for warm-season *Buchloë dactyloides* (buffalo grass) in Kansas (Fry et al., 1993). Many of these studies noted optimal planting dates varied some years (McGinnies, 1960; Bement et al., 1975; McGinnies, 1973; McLean and Wikeem, 1983); and Ries and Hofmann (1996) reported significant seeding date × year interactions for warm-season and cool-season grasses in North Dakota. Researchers have also documented that optimal planting dates varied for location (McGinnies, 1973; McLean and Wikeem, 1983).

Seeding date can be crucial for successful establishment of prairie species for many reasons. First, adequate growth is essential for seedlings to survive first-season drought (Hyder et al., 1971; Briske and Wilson, 1980), and to survive the first winter (White and Horner, 1943; White, 1984). Seeding date helps define the number of days a seedling has to mature during its first season. Second, planting when conditions are likely to be optimal for growth should, theoretically, improve establishment. Many regions have strong seasonal patterns of moisture and temperature, which restrict planting to certain seasons. Frasier et al. (1984) proposed a formula for selecting seeding date based on species' moisture requirements and the probability of receiving adequate rainfall. Third, seeding date can affect the amount and type of competing vegetation. Researchers have documented significantly more weed biomass in dormant fall plantings than in June plantings (Rodgers and Anderson, 1989); and restorationists have observed that weed competition is more severe in early spring than in late spring (Schramm, 1990). It is possible that planting during periods of slow weed germination and growth may lead to improved stand establishment of native grasses.

Studies on seeding date must also account for establishment differences between species. Researchers have noted that optimal seeding dates vary for different species (Kilcher, 1961; Ries and Hofmann, 1996); however, because establishment differences between species are often pronounced, species are usually analyzed separately and not compared statistically. Testing for a species effect would help to quantify establishment differences between C_3 and C_4 classes of grass. C_3 grasses are commonly thought to be easier to establish and to have a longer planting season than C_4 grasses. If this is true, increasing the percentage of cool-season grass in seed mixes may help improve stand establishment.

The goals of this study were to answer basic questions about the effect of seeding date on establishment, and to make recommendations that would be helpful in tallgrass prairie restoration. Specific objectives were to determine: 1) which planting dates result in best first-season and second-season establishment of prairie grasses in Minnesota, 2) whether dormant seeding of grasses is as successful as non-dormant seeding, 3) whether best planting dates differ between species, and 4) if increasing the percentage of cool-season grasses in a mix improves stand establishment.

METHODS

Study Site and Design

The study was conducted at the University of Minnesota, in St. Paul, Minnesota (44° 59'N, 93° 11'W). Annual precipitation in St. Paul averages 71.9 cm; mean annual temperature is 7.2 °C. Soils at the site are Waukegan silt loam: well-drained, mesic Typic Hapludolls that formed on outwash plains. Adjacent fields were planted in 1996 and 1997. Soil tests conducted by the University of Minnesota Soil Testing Laboratory showed both fields had soil pH 6.6. Bray-P was 100 ppm and K was 300 ppm in both fields, levels that are considered very high fertility for turfgrass. The field planted in 1996 had 4.6% organic matter and 1.4 ppm NO_3-N; the 1997 field had 6.3% organic matter and 8.0 ppm NO_3-N.

Each planting year a split-plot design with three replications was used to investigate seeding date (main-plot effect) and mix (subplot effect). Subplots were 3.7 m × 4.0 m. Ten seeding dates were tested each planting year, at nine to thirty-day intervals (Table 1-1); the last two seedings (late September and October) were considered dormant seedings and were not expected to germinate the year planted. Six mix treatments were studied. The mix treatments included four species planted as monocultures, a warm-season mix of the four species (81% weight warm-season grasses), and a cool-season mix of the four species (46% weight cool-season grasses) (Table 1-2). Species included C_4 warm-season grasses *Schizachyrium scoparium* (Michx.) Nash (little bluestem) and *Bouteloua curtipendula* (Michx.) Torr. (sideoats grama), and C_3 cool-season grasses *Elymus canadensis* L. (Canada wildrye) and *Bromus kalmii* A. Gray (Kalm's brome). Nomenclature follows Gleason and Cronquist (1991).

Seed for the experiment was obtained from Prairie Restorations, Inc., Princeton, Minnesota, and was stored at approximately 7 °C until used. In 1996, the seeding rate was 15.7 kg ha^{-1} bulk seed. For 1997, rates were converted to pure live seed (PLS) in order to make a more valid comparison between the two years. Differences in PLS were minor between three of the species: *S. scoparium* (7.2 kg ha^{-1}), *B. curtipendula* (7.3 kg ha^{-1}), and *B. kalmii* (6.7 kg ha^{-1}); *E. canadensis* was sown at a higher rate than other species (11.0 kg ha^{-1}).

Seedbed Preparation, Planting, and Maintenance

In May of each planting year, the field was tilled. Periodic mowing was done on plots that became weedy before their scheduled planting date. The goal for seedbed preparation was a tilled, weed-free plot with friable soil. Two of the plantings (July 30, 1996 and August 9, 1996) received an herbicide application of glyphosate approximately ten days prior to tilling. Use of herbicide was discontinued on subsequent plantings since the planting schedule was very precise and wind-free days were required for herbicide application. Because there were very few perennial weeds in the experiment fields, and because all plots were tilled and weed-free when seeded, using herbicide for two of the twenty planting dates should not compromise the experiment results.

On each planting date the following procedure was followed: tilled plots with tractor and tiller, packed soil with a manual drum roller, raked soil to loosen packed surface, manually broadcast seed, raked seed into soil, and packed plots with drum roller. To control weeds, plots were mowed with a flail mower or a riding mower when weeds reached 30 - 75 cm high.

Sampling and Analysis

Vegetation was sampled in September or October of the planting year (first-season establishment) and the following July (second-season establishment). A 1.00 m^2 frame was placed randomly in each plot and the number of target seedlings m^{-2} were counted. Weed seedlings were not tallied. Identification of grass seedlings is difficult and 100% accuracy is not always possible (Hitchcock et al., 1969). Accuracy in this experiment was high because only four species were planted, they were distinct from each other at the seedling stage, and they were fairly distinct from the weed species encountered. For example, notable characteristics of *B. curtipendula* include: shoot rolled in bud; pustules with single long hair along the leaf blade margin; ligule consisting of membrane with short hairs. *Panicum capillare* (witch grass), a non-native weed present on the site, is also rolled in the bud; however, the ligule in *P. capillare* consists of long hairs fused at the base, and its leaf blade pustules are small and indistinct. A key was developed to identify selected native and non-native grass seedlings (Chapter 3).

Analysis of variance (ANOVA) for split-plot design was conducted using SAS software (SAS Institute, 1996). To stabilize variances, data were transformed using the formula: Square root [y] + Square root [y+1]. The two planting years were analyzed separately, resulting in first-season and second-season ANOVA's for each planting year. Each ANOVA tested seeding date, mix, and seeding date × mix interaction. The error term for seeding date was block × seeding date. Tukey multiple comparison tests were conducted for seeding date and mix. The seeding date × mix interaction was explored by graphing establishment for all species across all seeding dates.

The University of Minnesota Weather Station, located approximately 100 yards from the experimental plots, provided data on precipitation, air temperature, and soil temperature.

RESULTS

Environmental Conditions

Rainfall patterns differed greatly each year of the experiment (Table 1-3). In 1996, relatively normal precipitation in May and June was followed by summer drought, with rainfall for July, August, and September totaling only 11.6 cm. 1997 was marked by spring drought and above average summer rainfall, with 46.2 cm rain for July, August, and September. In 1998, plots received above average June precipitation (18.0 cm). Mean monthly air and soil temperatures were relatively similar each year, except for May when mean monthly temperatures varied 6.1 °C during the three years studied.

Treatment Effects

Seeding date. Establishment patterns differed for the 1996 and 1997 plantings. For both planting years there were significant seeding date effects (p=0.0001) for first-season and second-season establishment; differences were highlighted by Tukey multiple comparison tests (Table 1-4). In 1996, first-season establishment for May through August plantings did not differ significantly from each other, but June and early July seeding dates were significantly better than September and October dates. By the second season, May and June 1996 seedings had significantly higher establishment than late-July through October seedlings, yielding an average of 11 seedlings m^{-2} for May and 15 seedlings m^{-2} for June (Figure 1-1). For 1997 plantings, late July through August dates had significantly higher first-season establishment than earlier plantings or dormant seedings. By the second-season, late July through early September 1997 planting dates averaged over 32 seedlings m^{-2} (Figure 1-2) and had significantly higher establishment than May, June, and late October plantings (Table 1-4).

Species. Establishment differed significantly for the species or mixes tested (p=0.0001), for both first and second-season establishment for both 1996 and 1997 plantings; differences were highlighted by Tukey multiple comparison tests (Table 1-5). For the 1996 plantings, *E. canadensis* had significantly better first and second-season establishment than all other species and mixes. The cool-season mix sown in 1996 had significantly higher seedling counts than *B. kalmii* and the warm-season materials. For the 1997 plantings, by the second season, *E. canadensis* again had significantly higher establishment than other species or mixes. However, establishment counts for *E. canadensis* and *B. kalmii* were close, averaging 43 seedlings m^{-2} and 37 seedlings m^{-2}, respectively, across the ten seeding dates (Figure 1-2). *B. kalmii* and the cool-season mix had significantly better establishment than the warm-season materials. *S. scoparium* and *B. curtipendula* had significantly poorer establishment than the other species or mixes, averaging only 2.5 and 3.8 seedlings m^{-2}, respectively, across the ten seeding dates (Figure 1-2).

Seeding date × mix. The seeding date × mix interaction was also statistically significant (p=0.0001, Figures 1-1 and 1-2). The trends followed those described for seeding date, with best establishment from early 1996 plantings and summer 1997 plantings. Two observations seemed particularly important. First, the latest planting date providing good second-season establishment (> 10 seedlings m^{-2}) for *S. scoparium* and *B. curtipendula* was August 8; the latest planting date providing good second-season establishment for *E. canadensis* and *B. kalmii* was September 10. Second, *S. scoparium* and *B. curtipendula* averaged ≤ 1 seedling m^{-2} from dormant seeding (Figures 1-1 and 1-2); in contrast, *E. canadensis* and *B. kalmii* established well from dormant seedings done late September 1997, averaging over 25 seedlings m^{-2} (Figure 1-2). *E. canadensis* also established well from the October 1997 planting, with over 40 seedlings m^{-2} (Figure 1-2).

Change in Composition of Mixes

Seedling mortality between the end of the first season and the middle of the second season (hereafter referred to as winter mortality) is shown in Table 1-6. For the 1996 plantings, winter mortality was 72.5% for *B. kalmii* and over 89.0% for all other species. For the 1997 plantings, warm-season grasses had winter mortality rates above 84.5%, but cool-season grasses had comparatively low mortality of 26.4% to 33.4%. The mixes experienced a shift in species composition from first to second season (Table 1-7). By the second season, C_3 grasses dominated both the warm-season and cool-season mixes.

DISCUSSION

Seeding Date and Environment

Establishment patterns differed greatly for the two planting years, and seeding date treatments significantly affected establishment. Second-season seedling counts showed May and June planting dates were favored in 1996, while late-July through early September dates were favored in 1997. Significant or notable seeding date effects have been previously reported in the central and north central United States (Rodgers and Anderson, 1989; Fry et al., 1993; Ries and Hofmann, 1996).

Establishment trends appeared to follow precipitation with plantings done during drought weeks (summer 1996 and spring 1997) having reduced establishment. Seedlings that established early in the season were often able survive summer drought the first year (May and June 1996 plantings), a phenomenon that was noted in early establishment studies (Cornelius, 1944) and one that is commonly observed in dry western states.

Plantings done during drought weeks, but receiving good subsequent rainfall, did not always result in good establishment. In 1997, for example, seedings done during the drought of May and June had poor establishment while seedings done a few weeks later, during weeks of substantial rainfall, had good establishment. McLean and Wikeem (1983) observed a similar pattern for *Agropyron desertorum* (crested wheatgrass) in British Columbia, where late June plantings received little moisture until fall and had poor establishment, while early fall plantings had good germination and establishment. These researchers speculated that June plantings had enough moisture to germinate but not to emerge. Moisture requirements for establishment of native grasses are not well documented but it has been shown that five wet days are sufficient for good germination and emergence of *B. curtipendula* in the field (Frasier et al., 1987). In the present experiment, daily rainfall patterns during June 1997 may support the scenario that seed never germinated or that seed germinated but seedlings could not emerge. However, it is also possible that seeds planted in May and June 1997 germinated, emerged, but seedlings perished shortly thereafter.

In this study there appeared to be little relationship between temperature and establishment. McLean and Wikeem (1983) also concluded temperature during the growing season did not seem to be a limiting factor in establishment of prairie grasses.

Mix and Seeding Date × Mix Effects

The experiment results confirm that species or mix are an important factor in stand establishment, supporting other studies that have noted establishment differences between species (Kilcher, 1961; Ries and Hofmann, 1996). The results also showed significant seeding date × species interactions, an effect that was documented by McGinnies (1960) for two cool-season grasses, *Agropyron desertorum* (crested wheatgrass) and *Bromus inermis* (smooth brome).

Several patterns differentiated C_3 and C_4 grasses. The warm-season grasses tested had: 1) lower establishment counts, 2) higher winter mortality, 3) a shorter planting season, and 4) lower establishment from dormant seeding.

Higher establishment for C_3 species. *E. canadensis* had significantly higher second-season counts than all other species or mixes. Though it was sown at a higher PLS rate than other species (approximately 1.5 times higher), it had a disproportionately higher number of seedlings m^{-2}, often over 10 times as many seedlings as the C_4 species tested (Figures 1-1 and 1-2). *S. scoparium* and *B. curtipendula* had significantly poorer establishment than all other species or mixes. For *S. scoparium* monocultures, by the end of the experiment only two of the 20 planting dates resulted in over 3 seedlings m^{-2} (Figures 1-1 and 1-2). This species has been cited as difficult to establish (Howell and Kline, 1992).

Results in this study support the commonly accepted generalization that C_3 prairie grasses are easier to establish than C_4 prairie grasses. Several traits seem to give C_3 grasses competitive advantages in early establishment. Researchers have documented higher root and shoot biomass for *E. canadensis* seedlings than for *B. curtipendula, Andropogon gerardii* (big bluestem) and *P. virgatum* (Robocker et al., 1953). Higher root weights for C_3 grass seedlings than for C_4 grass seedlings have also been reported (Qi and Redmann, 1993). Newman and Moser (1988b) showed that at the three-leaf stage *Elymus spp*. had many adventitious roots while *S. scoparium* had few; it is believed that adventitious roots are probably required for seedlings to survive drought and to survive winter (Hyder et al., 1971; Briske and Wilson, 1980). In addition, most C_4 grasses have a subcoleoptilar internode that elongates (thus placing the coleoptilar node just below the soil surface in a very dry zone), which may also account for establishment differences between C_3 and C_4 grasses (Hyder et al, 1971; Newman and Moser, 1988a).

Winter mortality. Seedling mortality rates between the first and second season differed for C_3 and C_4 species. Losses were high (over 89.0%) both years for *S. scoparium* and *B. curtipendula*. *E. canadensis* and *B. kalmii*, on the other hand, had high winter mortality for 1996 plantings and relatively low mortality for 1997 plantings (26.4% to 33.4%). The high losses in *E. canadensis* for winter 1996-1997 were largely accounted for by seedlings that emerged in late September 1996 and were only a few weeks old by the end of the growing season. If only the May, June, and early July 1996 plantings are considered, mortality for *E. canadensis* during winter 1996-1997 was 38.1%. Other researchers have documented low winter survival for C_3 grasses that emerged shortly before freeze-up (White and Horner, 1943), and have reported winter damage was significantly related to number of tillers, number of leaves, and plant weight in July and October (White, 1984).

Soil crusting may have contributed to mortality in the 1996 plantings. Summer drought in 1996, followed by spring drought in 1997, led to the formation of a thick soil crust with deep cracks in spring 1997. The cool-season grasses established in 1996 would have emerged in early spring 1997, before the thick crust formed, and not been strongly affected by the crust. Indeed, several plots of *E. canadensis* had over 30 plants m^{-2} and flowered. But established warm-season grasses generally emerge later in spring. These young plants, as well as newly-germinated seedlings of both C_3 and C_4 species, would have difficulty pushing through a thick soil crust and may have perished. Other researchers have also observed a thick soil crust restricting seedling emergence (Frischknect, 1951).

Length of planting season. The warm-season grasses tested had a 5-week shorter planting season than the cool-season grasses in 1997, a year with adequate summer moisture. In Minnesota, most restorationists do not seed native grasses after early or mid-July. The results of this experiment suggest that in years when moisture and other conditions are adequate, later planting may be possible: through August 8 for *S. scoparium* and *B. curtipendula*, and through September 10 for *E. canadensis* and *B. kalmii*. Ries and Hofmann (1996) documented successful August plantings for C_3 and C_4 grasses in central North Dakota, while Fry et al. (1993) had poor success with August planting of *B. dactyloides* in Kansas.

Dormant seeding. Dormant seeding of *E. canadensis* and *B. kalmii* was successful one of the two planting years. In 1996, *E. canadensis* germinated in late September and had extremely high winter mortality, suggesting that dormant seeding for this species should occur after late September. In this experiment, *S. scoparium* and *B. curtipendula* never established well from dormant seedings. Rodgers and Anderson (1989) also reported poor or reduced establishment for dormant seeding of some warm-season grass species. Researchers in North Dakota found dormant-seeded *P. virgatum* produced excellent stands the two planting years studied (Natural Resources Conservation Service, 1993). Dormant seedings of *S. nutans, Andropogon gerardii* (big bluestem) and *B. curtipendula* were successful one of two planting years; the second planting year, seeds of these species germinated in April, but seedlings perished after a late spring frost. Results from the present experiment suggest that further study is needed to determine what conditions are necessary for successful establishment of warm-season grasses from dormant seedings.

Change in Composition of Mixes

Lower first-season establishment and greater winter losses for the warm-season grasses led to a shift in species composition for the mixes. By the second season, C_3 grasses dominated both the warm-season and cool-season mixes. Tallgrass prairies are dominated by warm-season grass; therefore, a planting with predominantly cool-season grass will generally not be an acceptable outcome for a tallgrass prairie restoration. Many restorationists believe, however, that cool-season grasses such as *E. canadensis* decline after five to eight years and are replaced by other native species (i.e., Morgan, 1997). In fact, *E. canadensis* is sometimes used as a short-lived perennial cover crop (Liegel and Lyon, 1984; Morgan, 1997; Barry and Dana, 1998). Restorationists at the International Crane Foundation in Wisconsin followed a restoration over several years and reported that *E. canadensis* peaked the third season and declined the fourth season, *A. gerardii* increased each year, and *S. scoparium* and *S. nutans* maintained about the same level during the first five years (Liegel and Lyon, 1984). In Illinois restorations, Betz (1984) found that *S. nutans* was dominant by year four and *A. gerardii* dominated in following years.

Mixes with a high percentage of cool-season grass may help improve early stand establishment. They establish rapidly and will thus help prevent erosion sooner, they seem to compete well with weed seedlings, and they can quickly form stands that are aesthetically acceptable. However, additional reports are needed documenting long-term shifts in species composition for mixes with a high percentage of cool-season grass. It needs to be shown not only that *E. canadensis* and other cool-season grasses decrease over time, but that conservative warm-season species such as *S. scoparium* increase to adequate levels.

Recommendations and Conclusions

This study has provided experimental data that helps better define seeding dates for the tallgrass prairie region. While the exact dates may differ throughout the region, the patterns observed in this study are likely to apply to areas in the with similar rainfall and temperatures. Recommendations for Minnesota are as follows:

1. Planting dates for *Schizachyrium scoparium* and *Bouteloua curtipendula* are May 1 through July 20. If moisture is adequate, these dates may be extended through early August (August 8 in this experiment), resulting in a 14-week planting season.
2. Planting dates for *Elymus canadensis* and *Bromus kalmii* are May 1 through August 1. If moisture is adequate, these dates may be extended through early September (September 9 in this experiment), resulting in a 19-week planting season.
3. Dormant seedings of *E. canadensis* and *B. kalmii* may be planted after mid-October. Dormant seedings of *S. scoparium* and *B. curtipendula* did not establish well in this experiment.

The experiment results support previous findings that: 1) seeding date is an important factor in successful establishment of prairie and rangeland grasses; and 2) preferred seeding dates vary for each year and for each species. Establishment appeared to relate to rainfall patterns during the planting year.

In addition, several establishment differences were documented for C_3 and C_4 prairie grasses. The C_4 grasses tested had: 1) lower first-season and second-season establishment, 2) higher winter mortality, 3) a shorter planting season, and 4) poor establishment from dormant seeding. There was a change in composition of the mixes between the first and second season, and by the second season C_3 grasses dominated both the cool-season mix and the warm-season mix. This study suggests that restorationists can manipulate seeding dates and adjust seed mixes to improve establishment of prairie grasses.

Table 1-1. Dates for seeding prairie grasses in St. Paul, Minnesota over two years.

Year	Seeding Dates									
1996	5/22	6/13	7/12	7/30	8/9	8/19	8/29	9/9	9/23	10/21
1997	5/22	6/13	7/15	7/30	8/8	8/19	8/29	9/10	9/23	10/17

Table 1-2. Composition of two different prairie grass mixtures planted in St. Paul, Minnesota in 1996 and 1997.

Species	% of PLS for Each Species in Mix	
	Warm-season Mix	Cool-season Mix
Schizachyrium scoparium	53.6	25.5
Bouteloua curtipendula	27.6	20.7
Elymus canadensis	8.4	31.5
Bromus kalmii	10.3	22.4

Table 1-3. Total monthly precipitation for St. Paul, Minnesota, 1996 - 1998 and 30-year norm.

	Total Monthly Precipitation (in cm)			
Month	1996	1997	1998	30-year norm
January	4.37	4.01	2.34	2.11
February	0.56	0.46	2.34	2.16
March	2.97	2.26	10.85	4.06
April	2.41	2.36	4.29	5.51
May	8.48	3.73	10.46	8.59
June	11.20	11.89	18.03	10.59
July	4.55	26.39	5.46	9.02
August	3.45	13.59	–	8.64
September	3.63	6.25	–	7.34
October	8.36	5.56	–	5.11
November	12.07	1.80	–	3.68
December	3.38	0.30	–	2.39
Annual total	65.43	78.60	N/A	69.20

Table 1-4. Effects of ten seeding dates on establishment of prairie grasses.*

Year Planted	Establishment Season	Planting Date									
		5/22	6/13	7/12	7/30	8/9	8/19	8/29	9/9	9/23	10/21
1996	1st season	8.8ab	10.4a	11.0a	10.1ab	8.3abc	9.3ab	7.8abc	6.8bc	4.9c	1.0d
1996	2nd season	5.6ab	7.2a	4.2bc	3.2cd	2.0d	1.9d	1.9d	1.5d	1.4d	2.0d
1997	1st season	1.9e	2.4de	8.0cd	16.3a	20.1a	15.7ab	18.3a	10.2bc	1.0e	1.0e
1997	2nd season	2.0b	2.1b	6.5ab	10.5a	11.5a	9.8a	9.8a	9.8a	7.0ab	4.6b

*Values represent the mean number of seedlings m^{-2}, transformed by: SQRT[y] + SQRT[y+1]. Within a row, values with the same letter do not differ significantly ($p < 0.05$), as determined by Tukey multiple comparison tests.

Table 1-5. Effects of four monocultures and two mixes on establishment of prairie grasses.*

Year Planted	Establishment Season	*Schizachyrium scoparium*	*Bouteloua curtipendula*	*Bromus kalmii*	*Elymus canadensis*	Warm-season Mix	Cool-season Mix
		Species and Mixes					
1996	1st season	4.8d	4.7d	3.6d	17.7a	6.6c	9.6b
1996	2nd season	1.9d	2.1cd	1.8d	5.9a	2.8c	4.0b
1997	1st season	7.8cd	7.3d	10.4ab	11.8a	9.2bc	10.5ab
1997	2nd season	2.1d	2.9d	10.0b	12.2a	6.9c	10.1b

*Values represent the mean number of seedlings m^{-2}, transformed by: SQRT[y] + SQRT[y+1]. Within a row, values followed by the same letter do not differ significantly ($p < 0.05$), as determined by Tukey multiple comparison tests.

Table 1-6. Seedling mortality of prairie grasses from first to second season.*

	Percent Mortality	
Species	1996 plantings	1997 plantings
Schizachyrium scoparium	89.8%	91.85%
Bouteloua curtipendula	89.4%	84.5%
Elymus canadensis	89.7%	33.4%
Bromus kalmii	72.5%	26.4%

*Values are based on mean number of seedlings m^{-2} for monocultures and include data from all seeding dates except the September and October dormant seedings.

Table 1-7. Change in species composition of prairie grass mixes from first to second season.*

Year Planted	Species	Warm-season Mix		Cool-season Mix	
		1st season % of mix	2nd season % of mix	1st season % of mix	2nd season % of mix
1996	*Schizachyrium scoparium*	33.6	18.5	7.9	2.2
	Bouteloua curtipendula	28.3	8.6	10.4	2.2
	Elymus canadensis	37.1	65.4	77.9	89.4
	Bromus kalmii	0.9	7.4	3.8	6.1
	Total	99.9	99.9	100.0	99.9
1997	*Schizachyrium scoparium*	51.7	1.9	19.4	0.4
	Bouteloua curtipendula	17.6	3.5	10.1	0.5
	Elymus canadensis	19.0	47.4	31.4	32.6
	Bromus kalmii	11.7	47.2	39.0	66.4
	Total	100.0	100.0	99.9	99.9

*Values are based on the mean number of seedlings m^{-2} for all ten planting dates.

Figure 1-1. Second-season establishment for plantings done in 1996. Values indicate the mean number of seedlings m^{-2} for six species or mixes on ten seeding dates.

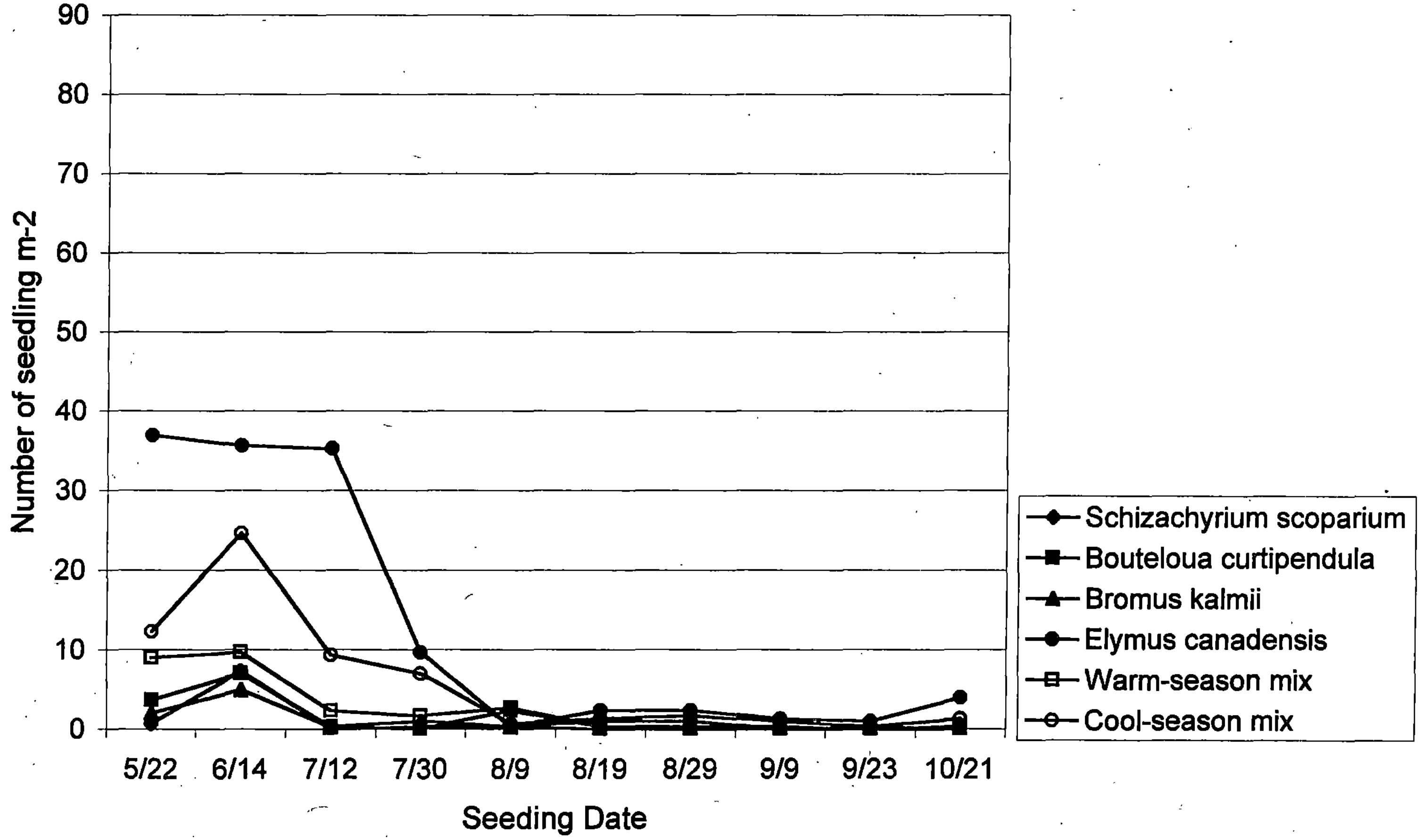
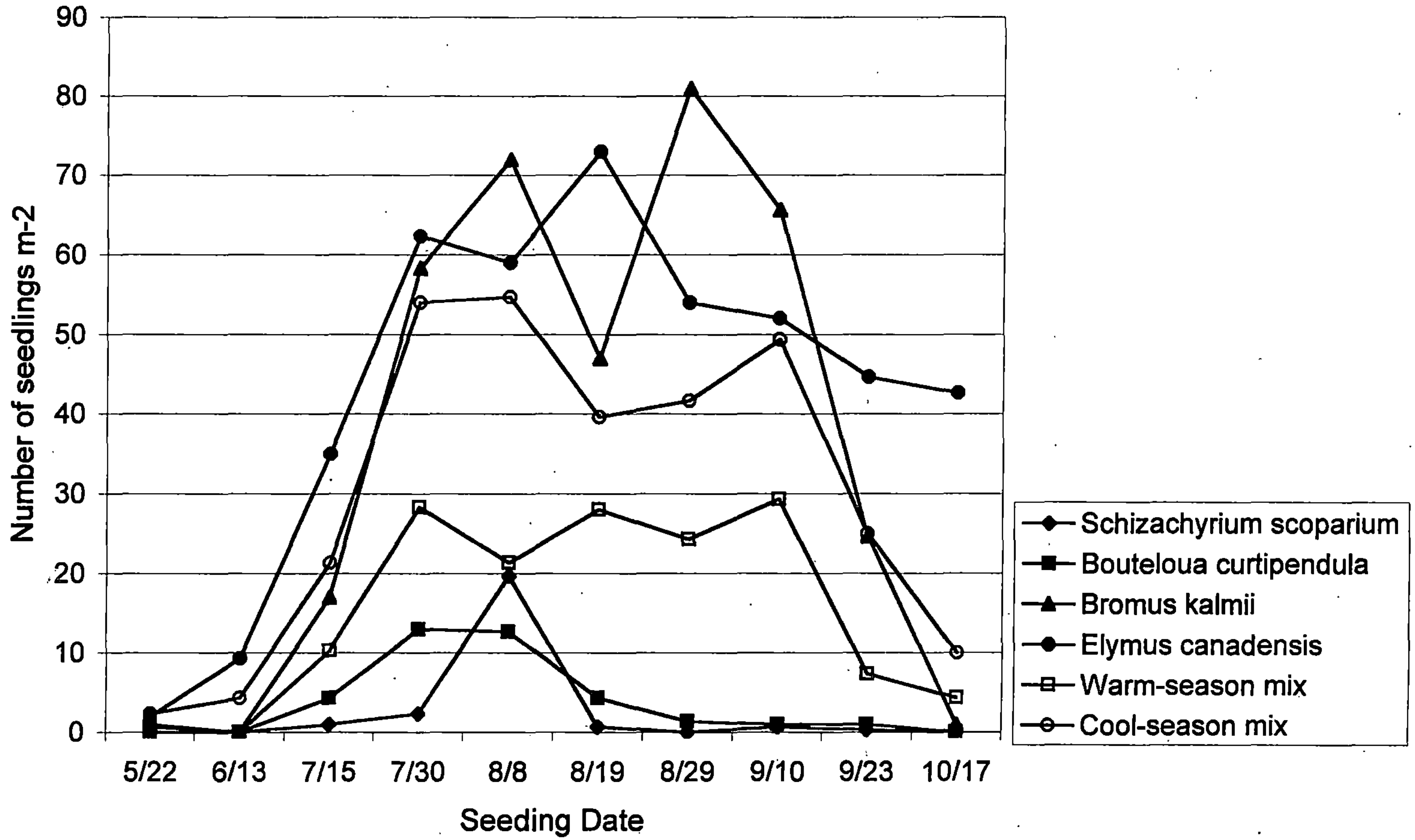


Figure 1-2. Second-season establishment for plantings done in 1997. Values indicate the mean number of seedlings m^{-2} for six species or mixes on ten seeding dates.



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CHAPTER 2

Effects of Seeding Date and Mix on Establishment of Two MN/DOT Mixes

ABSTRACT

Proper seeding time is crucial for successful stand establishment of prairie grasses and ideal planting time may vary for species. This experiment investigated the effects of seeding date and species or mix on first and second-season establishment of prairie grasses. In 1997, four seeding dates were tested (June 13, July 12, August 9, and September 23), at the University of Minnesota, St. Paul. Two mixes were evaluated: a warm-season grass mix used by the Minnesota Department of Transportation, which consisted of 74% warm-season grasses, and a cool-season modification of that mix with 47% cool-season grasses.

By the second-season, there were statistically significant effects for seeding date, mix, and seeding date × mix interaction. There was no significant difference in establishment for July, August, and dormant September plantings; the June seeding date resulted in significantly lower establishment than other dates. Establishment patterns appeared to relate to rainfall patterns during the planting year.

The cool-season mix had significantly higher seedling counts than the warm-season mix, but contained few warm-season grass seedlings. Species composition of the mixes shifted between first and second season with percentages increasing for *Elymus canadensis* (Canada wildrye), *E. trachycaulus* (slender wheatgrass), *Andropogon gerardii* (big bluestem), and percentages decreasing for *Schizchyrium scoparium* (little bluestem), *Bouteloua curtipendula* (sideoats grama), *Sorghastrum nutans* (Indian grass), and *Panicum virgatum* (switchgrass).

Key words: prairie restoration, establishment, seeding date, native grasses, *Elymus canadensis*, *Elymus trachycaulus*, *Andropogon gerardii*, *Schizachyrium scoparium*, *Bouteloua curtipendula*, *Panicum virgatum*, *Sorghastrum nutans*.

INTRODUCTION

Restorationists have long understood that there are establishment differences between species. Seeding date studies have shown that optimal planting dates may differ for different species (McGinnies, 1960; Kilcher, 1961; Ries and Hofmann, 1996); and the experiment presented in Chapter 1 (hereafter referred to as the U of MN study) documented significant differences in establishment across species. A second study – reported here and referred to as the Minnesota Department of Transportation (MN/DOT) experiment – was undertaken to provide data on additional species not included in the U of MN seeding date study.

The MN/DOT study tested one planting year, four seeding dates, and two mixes, while the U of MN study tested two planting years, ten seeding dates, four monocultures and two mixes. The mixes in the MN/DOT study included a warm-season mesic prairie mix used by the MN/DOT, and a cool-season modification of that mix. Because only one planting year was tested, the MN/DOT experiment is best interpreted in conjunction with the U of MN study; and the discussion that follows highlights similarities, differences, and new information provided by the MN/DOT study.

Specific objectives of this experiment were to determine: 1) whether seeding date affects first-season and second-season establishment of prairie grasses; 2) whether dormant seeding is as successful as non-dormant seeding; and 3) if increasing the percentage of cool-season grasses in a mix improves stand establishment.

METHODS

Study Site and Design

The study was conducted May 1997 through July 1998, at the University of Minnesota, in St. Paul, Minnesota (44° 59'N, 93° 11'W). Annual precipitation in St. Paul averages 71.9 cm; mean annual temperature is 7.2 °C. The University of Minnesota Weather Station (located approximately 100 yards from the experimental plots) recorded precipitation. Drought in May and June 1997, was followed by above average summer rainfall (42.6 cm rain for July, August, and September) (see Table 1-3, p. 17).

Soils at the site are Waukegan silt loam: well-drained, mesic Typic Hapludolls that formed on outwash plains. Soil tests conducted by the University of Minnesota Soil Testing Laboratory showed a pH of 6.6, 100 ppm Bray-P, 300 ppm K, 6.3% organic matter, and 8.0 NO_3-N ppm.

A split-plot design with three replications was used to investigate seeding date (main-plot effect) and mix (subplot effect). Subplots were 3.7 m × 4.0 m. Four seeding dates were tested in 1997: June 13, July 12, August 9, September 23. The September planting was considered a dormant seeding and was not expected to germinate until the following spring. Two seed mixes were evaluated: a warm-season mix consisting of 74.4% C_4 grasses, 10.5% C_3 grass, and 15.1% inert or weed material; and a cool-season version of this mix created by increasing the percentage of cool-season grasses to 47.0%. Table 2-1 specifies the percentage of each species in the mixes.

Seed was from Prairie Restorations, Inc., Princeton, Minnesota, and was stored at approximately 7 °C until used. The seeding rate was 15.7 kg ha^{-1} pure live seed.

Seedbed Preparation, Planting, and Maintenance

The site was tilled in May. Periodic mowing was done on plots that became weedy before their scheduled planting date. The goal for seedbed preparation was a tilled, weed-free plot with friable soil. Since the site had few perennial weeds, tilling was adequate soil preparation. The following methods were used for each planting date: tilled plots with small tractor and tiller, packed soil with manual drum roller, raked soil to loosen packed surface, manually broadcast seed, raked seed into soil, packed plots with drum roller. To control weeds, plots were mowed with a flail mower or a riding mower when weeds reached 30 - 75 cm high.

Sampling and Analysis

Vegetation was sampled in October 1997 (first-season establishment) and July 1998 (second-season establishment). A 1.00 m^2 frame was placed randomly in each plot, plants were clipped or pulled below the crown, and the number of target seedlings m^{-2} were counted. Weed seedlings were not tallied. Identification of grass seedlings is difficult and 100% accuracy is not always possible (Hitchcock et al., 1969). A key was developed to identify selected native and non-native grass seedlings (Chapter 3). When necessary, a dissecting scope was used to aid in identification.

Analysis of variance (ANOVA) for split-plot design was conducted for first and second-season establishment using SAS software (SAS Institute, 1996). To stabilize variances, data were transformed using the formula: Square root [y] + Square root [y+1]. Each ANOVA tested seeding date, mix, and seeding date × mix interaction. The error term for seeding date was block × seeding date. Tukey multiple comparison tests were then conducted for seeding date and mix. The seeding date × mix interaction was explored by graphing establishment for all species across all seeding dates.

RESULTS

Seeding date treatments significantly affected both first-season and second-season establishment ($p=0.0001$ and $p=0.0019$, respectively, Table 2-2). By the second season, the July, August, and September seedings had significantly better establishment than the June seeding (Table 2-3).

Effects of mix were not significant the first season; however, by the second season the mix effect was significant ($p=0.0001$, Table 2-2), with the cool-season mix having significantly more seedlings m^{-2} than the warm-season mix (Table 2-4). The seeding date

× mix interaction was also significant by the second season ($p=0.0216$, Table 2-2). For July and August plantings, the cool-season mix had over 1.5 times as many seedlings as the warm-season mix; for September dormant seeding, the cool-season mix outperformed the warm-season mix, having over 4 times as many seedlings (Figure 2-1).

Species composition of both mixes changed from first to second season (Table 2-5). The percentage of *E. canadensis*, *E. trachycaulus*, and *A. gerardii* seedlings m^{-2} increased from first to second season, while all other species decreased.

DISCUSSION

Results in the MN/DOT experiment were similar to results for 1997 in the U of MN study. Early stand establishment appeared to follow precipitation with relatively low second-season establishment from plantings done during June drought (< 11 seedling m^{-2}, Figure 2-1), and excellent establishment from July and August plantings (> 30 seedling m^{-2}, Figure 2-1), which received high rainfall. These results show that in a year with adequate moisture, July and early August plantings can be very successful in Minnesota. Successful August planting of C_3 and C_4 grasses have been documented for central North Dakota by Ries and Hofmann (1996), while Fry et al. (1993) had poor success with irrigated August plantings of *B. dactyloides* in Kansas.

Better establishment for the cool-season mix than for the warm-season mix (46 seedlings m^{-2} vs. 23 seedlings m^{-2}, Figure 2-1) also supported results from the U of MN experiment. The superiority of the cool-season mix was especially notable for the September dormant seeding, where the cool-season mix averaged 57 seedlings m^{-2} vs. 13 seedlings m^{-2} for the warm-season mix (Figure 2-1). Dormant seeding of warm-season grasses resulted in poor establishment in the U of MN study as well (< 1 seedling m^{-2}, Figures 1-1 and 1-2, pp. 22-23).

The change in species composition of mixes from first to second season (Table 2-5) helps explain establishment differences between species. In both mixes, the percentage of C_3 grasses increased from first to second season, while the percentage of C_4

grasses decreased – except for *A. gerardii*. The cool-season mix began with 40% warm-season grass seed (Table 2-1), but by the second season, warm-season grasses comprised only 5% of the native seedlings present in the cool-season mix (Table 2-5). This raises the same concerns that were voiced in Chapter 1: will a cool-season mix generate an adequate number of warm-season grass seedlings the first season to eventually develop into a stand of predominantly warm-season grass?

The MN/DOT experiment provides data on four species not included in the U of MN study. *E. trachycaulus* is used frequently on MN/DOT projects but is less common in other restorations done in this region. This C_3 grass had very vigorous growth in the experiment. It was the dominant species in both the warm-season mix and the cool-season mix, despite the fact that it was sown at a lower rate than *E. canadensis*. For both *E. trachycaulus* and *E. canadensis*, it is crucial to document long-term establishment trends. If these species decrease and are successfully replaced by warm-season grasses, they may merit an important role in some restorations.

Four of the warm-season grasses in this mix – *S. scoparium*, *B. curtipendula*, *S. nutans*, and *P. virgatum* – had low first-season establishment and poor winter survival. *A. gerardii*, on the other hand, had a dramatic increase in number of seedlings m^{-2} between first and second season in the warm-season mix. This was not unexpected since *A. gerardii* is often considered one of the easier warm-season grasses to establish and other researchers have documented increases in this species after the first growing season (Liegel and Lyon, 1984). However, it does highlight the fact that not all C_4 grasses have similar establishment patterns, and caution must be taken when making generalizations. In addition, it is striking that *A. gerardii's* great increase in the warm-season mix (3.8% the first season to 24.3% the second season) was not matched in the cool-season mix (2.7% to 3.8%, Table 2-5). This suggests that *A. gerardii* competed more successfully against warm-season native grasses and weed species than it did against *E. trachycaulus* and/or *E. canadensis*. It is not known whether, once established, *A. gerardii* continues to dominate or if more conservative warm-season grasses eventually prevail.

Conclusions

This study confirmed results of Chapter 1, finding that seeding date was an important factor in successful establishment of prairie grasses and that establishment appeared related to rainfall patterns during the planting year. The cool-season mix had higher seedling counts than the warm-season mix, but the cool-season mix contained few C_4 grasses by the second season. *A. gerardii* did not follow the same trends as other C_4 grasses, indicating that while some trends may exist for C_3 vs. C_4 species, it is important to consider performance of individual species.

This work points to the need for additional studies documenting long-term shifts in species composition of mixes, and determining factors that contribute to successful dormant seeding of warm-season grasses in the northern Great Plains.

Table 2-1. Composition of a warm-season mix and a cool-season mix planted in St. Paul, Minnesota in 1997.*

Scientific Name	Common Name	C_3 or C_4 Species	Warm-season Mix	Cool-season Mix
Andropogon gerardii Vitman	big bluestem	C_4	21.33%	11.90%
Sorghastrum nutans (L.) Nash	Indian grass	C_4	17.70%	10.44%
Bouteloua curtipendula (Michx.) Torr.	sideoats grama	C_4	18.37%	10.83%
Schizachyrium scoparium (Michx.) Nash	little bluestem	C_4	12.29%	7.01%
Panicum virgatum L.	switch grass	C_4	4.71%	3.01%
Elymus canadensis L.	Canada wildrye	C_3	6.35%	28.24%
Elymus trachycaulus (Link) Gould	slender wheatgrass	C_3	4.17%	18.72%
	weed seed	both	0.06%	0.04%
	inert, etc.	both	15.03%	9.80%

*Percentages indicate the percentage of pure live seed, by weight. Nomenclature follows Gleason and Cronquist (1991).

Table 2-2. Results of split-plot analysis of variance showing effects of seeding date and mix treatments on establishment of prairie grasses.

Data For	Year	R^2	Effects	*p*
1st season establishment	1997	.98	seeding date	.0001
			mix	.0963
			seeding date × mix	.2768
2nd season establishment	1997	.96	seeding date	.0019
			mix	.0001
			seed date × mix	.0216

Table 2-3. Effects of four seeding dates on establishment of prairie grasses, 1997-1998.*

Data For	Seeding Date			
	6/13	7/12	8/9	9/23
1st season establishment	3.2 c	15.7 b	21.9 a	1.0 c
2nd season establishment	5.9 b	12.2 a	14.9 a	11.2 a

*Values represent the mean number of seedlings m^{-2} transformed by (SQRT[y] + SQRT[y+1]). Within a row, values with the same letter do not differ significantly ($p < 0.05$), as determined by Tukey multiple comparison tests.

Table 2-4. Effects of two mixes on stand establishment of prairie grasses, 1997-1998.*

Data For	Warm-season Mix	Cool-season Mix
1st season establishment	9.7 a	11.2 a
2nd season establishment	9.2 b	13.0 a

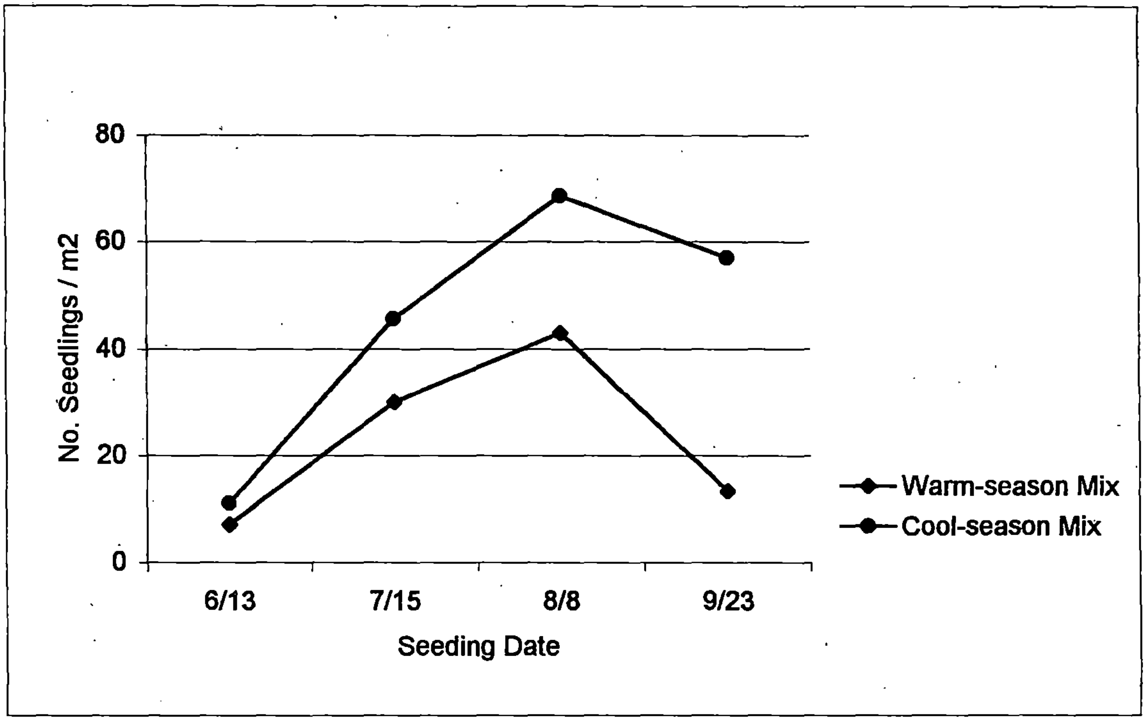
*Values represent the mean number of seedlings m^{-2} transformed by (SQRT[y] + SQRT[y+1]). Within a given row, values followed by the same letter do not differ significantly ($p < 0.05$), as determined by Tukey multiple comparison tests.

Table 2-5. Change in species composition of two prairie grass mixes from first season (1997) to second season (1998).*

Species	Warm-season Mix		Cool-season Mix	
	1st Season % of Mix	2nd Season % of Mix	1st Season % of Mix	2nd Season % of Mix
Andropogon gerardii	3.8	24.3	2.7	3.8
Sorghastrum nutans	6.9	3.9	1.2	0.5
Bouteloua curtipendula	16.9	8.6	4.7	0.2
Schizachyrium scoparium	28.3	3.6	12.0	0.5
Panicum virgatum	28.1	0.4	11.4	0.0
Elymus canadensis	1.7	11.4	9.9	18.5
Elymus trachycaulus	14.2	47.9	58.2	76.4
Total	99.9	100.1	100.1	99.9

*Values are based on mean number seedlings m^{-2} for all four seeding dates.

Figure 2-1. Second-season establishment for warm-season mix and cool-season mix. Values indicate the mean number of seedlings m^{-2}.



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CHAPTER 3

A Field Key for Identifying Seedlings of Fifteen Grass Species

ABSTRACT

Identification of grasses without floral parts is a challenge. In prairie restoration, the ability to identify grass species in the seedling stage is necessary for determining if a planting has been successful. Fifteen common grasses, native and non-native taxa, were grown in the greenhouse and analyzed as seedlings. A key and field guide are presented here as tools to identify these desirable and weedy grasses. This information should be useful to students in basic turfgrass or ecology classes, as well as to restorationists.

Key words: native grass, seedling identification, prairie restoration.

INTRODUCTION

The great interest in prairie gardens and restorations has increased the need for an ability to identify grasses. This ability is especially critical in evaluating the success of plantings. Because few prairie grasses flower the year of seeding, evaluating young plantings requires identification of grasses in the seedling and juvenile phases. Most botanical keys for the grass family are based on floral structures, which are unique for each species (Hitchcock, 1950). Identifying grasses without floral parts is a challenge (Hitchcock et al., 1969; Harrington, 1977). Vegetative characteristics are not as definitive as floral characteristics (Pohl, 1978); and for a given species they may vary due to genetic differences or due to a plant's response to its environment.

Despite the difficulties of identifying immature grasses, several vegetative keys for grasses have been published. Hitchcock et al. (1969) developed a key to the grasses of the Pacific Northwest that focused on gross morphological features, relying heavily on ligules. A guide to the prairie grasses of Canada also used morphological characteristics (Best et al., 1971). Burr and Turner (1933) included an anatomical key in their guide to British grasses, with diagrams of stem cross-sections. In the early 20th century, agricultural agencies in the United States prepared many regional and state vegetative keys for grasses (Harrington, 1977).

Many of the existing keys are lengthy and require using a dissecting scope or microscope. This is time-consuming and often impractical for restorationists and landscape contractors, who require a key that uses characteristics easily seen with the naked eye in field conditions.

Goals and Objectives

The goal of this project was to develop a key and an easy-to-use field guide for identifying prairie grass seedlings. Specific criteria were that the key and guide:

1. Include native prairie grasses that are commonly planted in restorations in the Northern Great Plains.
2. Include non-native grasses that are common weeds in restorations in the Northern Great Plains.
3. Use characteristics that are easy to observe in field conditions.
4. Describe plants that have at least three to six leaves and have not yet flowered.
5. Use characteristics that do not require removing the plant or parts of the plant.
6. Require use of a magnifying lens or dissecting scope only as a last resort.
7. Be brief and be easy to use in the field.
8. Be useful for professionals and amateurs evaluating prairie restorations.

METHODS

The fifteen species of grasses studied are listed in Table 3-1. Nomenclature follows Gleason and Cronquist (1991). Eight of the species were native prairie grasses commonly seeded on restorations in the tallgrass prairie region. Seven were non-native species that are often present in the weed seedbanks of prairie restorations. Seed for the native grasses was obtained from Prairie Restorations, Inc., Princeton, Minnesota. Seed for the non-native grasses was collected within 30 miles of St. Paul, Minnesota.

In February through May 1998, seeds were sown in flats and placed in a greenhouse at the University of Minnesota, St. Paul. No stratification or other pre-seeding treatment was done. Seedlings were transplanted into 4-inch pots after they had at least one true leaf. As seedlings developed they were observed, photographed, and pressed. All observations were made on seedlings less than ten weeks old. Photographic equipment included: 1) a Wild Leitz MPS46/52 photoautomat mounted on a Wild Leitz M3Z stereomicrosope (magnification: 10X, 16X, 25X, 40X); 2) a Canon EOS Rebel X camera with 35-80mm zoom lens; and 3) a Hoya 52mm +4 magnifying lens attachment for the Canon EOS Rebel X camera.

Many of the grasses in this study were also observed in the field to compare characteristics of greenhouse and field-grown seedlings. Important distinguishing characteristics (auricles, ligules, rolled or folded shoots) did not differ between greenhouse and field-grown specimens. The most significant differences observed were:

1. Length of internodes. Field-grown specimens tended to have shorter internodes than their greenhouse-grown counterparts. This gave the plants a stockier, stronger look.
2. Color. There was often more pink, maroon, or purple coloration in field-grown plants.
3. Hairiness. Plants in the field were sometimes hairier.

VEGETATIVE CHARACTERISTICS OF GRASSES

An understanding of grass terminology is necessary for using the key. Figures 3-1 and 3-2 illustrate the vegetative structures of grass.

The stems of a grass plant are called *culms*. A culm may send out *tillers* – shoots that are generally erect. Two types of non-aerial stems are also common in grasses: *rhizomes* are underground stems, and *stolens* are stems that trail along the surface of the ground and root at the nodes.

A culm consists of *nodes* (joints), *internodes* (area between joints), and *leaves*. Each leaf consists of a *sheath* (portion that encircles the culm) and a *blade*. The junction of the sheath and the blade is referred to as the *collar*. The collar usually includes a *ligule* and sometimes includes *auricles* (Figure 3-2).

Characteristics Used in the Key

Identification of grass seedlings requires observation of several different features. This identification key begins with large structures and easy-to-distinguish characteristics. For example, in *Schizachyrium scoparium* the flatness of the lower stems is a quickly visible characteristic. In *Elymus canadensis* the claw-like clasping auricle is a notable feature. Below is a discussion of the primary structures used for identification in this key.

Auricle. Auricles are very distinct in some grass species. Claw-like clasping auricles in particular are easy to see (Figure 3-3). Even for a species with auricles, not every leaf will have an auricle so it is important to check several leaves. In addition, these structures are delicate and easily broken (Hitchcock et al., 1969). The key begins by separating species with and without claw-like auricles.

1. *Auricles present* – Some leaves have an easily visible claw-like, clasping auricle (Figure 3-3).
2. *Auricles absent* – No leaves have a claw-like, clasping auricle (Figure 3-4).

Leaf. Many keys or descriptions of grasses distinguish between leaves or shoots being *rolled in the bud* or *folded in the bud.* This refers to the new emerging leaves, which are near the top of the culm. The lengthwise edge of a young leaf – not the tip of the leaf – will seem to unroll smoothly or it will have the creases of a fold. For the species investigated, a three-class breakdown was more appropriate than the traditional two-class breakdown of rolled vs. folded.

1. *Rolled* – The leaf is rolled in the bud. The margin of a newly emerging leaf appears rolled or involute (Figure 3-5).
2. *Folded in half* – The new leaf is folded in half lengthwise, with the margins touching each other (Figure 3-6).
3. *Folded* – The new leaf is folded, but not in half. At first glance the leaf may appear rolled, but careful observation of the lengthwise edge reveals slight lengthwise creases where the leaf is unfolding.

Culm. In young grass seedlings, it is sometimes useful to distinguish between cylindrical stems or culms and flat stems or culms. When viewing the stem, consider the lower portion of the culm, near the base of the plant. Some species are distinctly and consistently flat or cylindrical, others are more difficult to classify. As plants mature, flatness of culms will generally be less pronounced and may not be a useful distinguishing characteristic.

1. *Cylindrical* – The culms at the base of the plant are cylindrical. A cylindrical culm rolls or twirls easily between thumb and third finger.
2. *Flat* – The culms at the base of the plant are flat. A flat culm will not roll easily between thumb and finger (Figure 3-7).

This characteristic of being flat or cylindrical is often related to vernation. *Vernation* refers to the way leaf blades are rolled in the sheath. It is classified by looking at a cross-section of the culm taken below the collar and determining whether the new leaves are conduplicate (folded), clasping, or rolled (for diagrams and descriptions see Harrington, 1977). Vernation was not used in the key since it is not practical for quick identification in the field. However, the shape of the cross-section, which is related to vernation, was sometimes distinguished. Three shapes were noted:

1. *Circle* – The cross-section is round.
2. *Ellipse* – The cross-section is oval or elliptical.
3. *Eye-shaped* – The cross-section comes to a point at one or both ends.

Ligule. Ligules typically have a fairly consistent form within a species and are a very useful identifying characteristic. While, the shape, color and margins of a ligule are usually consistent for a species, the length may vary (Best et al., 1971; Hitchcock et al., 1969). Hitchcock et al. (1969) provide excellent illustrations of ligules and auricles in their vegetative key for grasses. Ligules are usually visible with the naked eye, however, a dissecting scope may be necessary to see the details. Therefore, in this study, ligules were used as a later step in classification. Four classifications were used for ligules.

1. *Absent* – Ligule is absent or difficult to detect. Most grass species have a ligule (Figure 3-8).
2. *Membrane* – The ligule is a membranous tissue (Figure 3-9).
3. *Fringe of hairs* – With the naked eye the ligule appears to be a fringe of hairs. These hairs may actually arise from a very short strip of membranous tissue (Figure 3-10).
4. *Membrane with hairs* – The ligule consists of a strip of membranous tissue with a fringe of hairs. Both the tissue and the hairs are visible.

Hair. Hairiness is generally avoided in identification keys because of variability within a species or environment. However, some hair patterns may be very useful in identification. In particular, some species have long hairs protruding from pustules along the margin of the leaf (Figure 3-11, Figure 3-4). If the light is adequate, the hairs and pustules can be seen in the field with the naked eye. Other species may have hairs spaced along the sheath margin (Figure 3-3), or abundant hairs at the collar (Figure 3-10).

Color. Color varies within a species and can change with environment; thus, it is generally avoided as a descriptor. However, in the field many people use color as an aid, especially if they have a single seed source. In this study *Bouteloua curtipendula* was always a dark green, *Poa pratensis* was a bright green, and young *Bromus kalmii* seedlings were olive green, characteristics that helped distinguish them from other species.

Rhizome. Rhizomes are usually absent on very young plants and seedlings must be pulled from the soil to determine whether they are present (Figure 3-12). Therefore, in the key, rhizomes were used only when a plant could not be distinguished by other characteristics.

Sheath. Closed or open sheath is a characteristic used in some keys. It was found that sheaths often overlapped on very young seedlings and opened with age. Thus, this characteristic is sometimes misleading and was not used in the descriptions or key.

1. *Closed sheath* – The sheath is tubular or the margins on the sheath overlap.
2. *Open sheath* – The margins of the sheath do not overlap; the sheath appears to be split or cut.

KEY AND FIELD GUIDE

The key is presented in Figure 3-13. It was reformatted to create a two-page field guide that was easier to use in the field. Part A of the field guide is a modified version of the key (Figure 3-14). Part B of the guide summarizes key characteristics for each species (Figure 3-15). Because this study investigated only 15 species, the user must be careful not to force a plant to fit a description.

Table 3-1. Native and non-native grasses used in developing identification key and field guide.

Scientific Name	Common Name
Native Grasses	
Andropogon gerardii Vitman	big bluestem
Bouteloua curtipendula (Michx.) Torr.	sideoats grama
Bromus kalmii A. Gray	Kalm's brome
Elymus canadensis L.	Canada wildrye
Elymus trachycaulus (Link) Gould	slender wheatgrass
Panicum virgatum L.	switch grass
Schizachyrium scoparium (Michx.) Nash	little bluestem
Sorghastrum nutans (L.) Nash	Indian grass
Non-native Grasses	
Elytrigia repens (L.) Nevski	quack grass
Bromus inermis Leysser.	smooth brome
Digitaria sanguinalis (L.) Scop.	crabgrass
Echinochloa crusgalli (L.) P. Beauv.	barnyard grass
Panicum capillare L.	witchgrass
Poa pratensis L.	Kentucky bluegrass
Setaria viridis (L.) P. Beauv.	green foxtail

Figure 3-1. Vegetative structures of a grass plant.

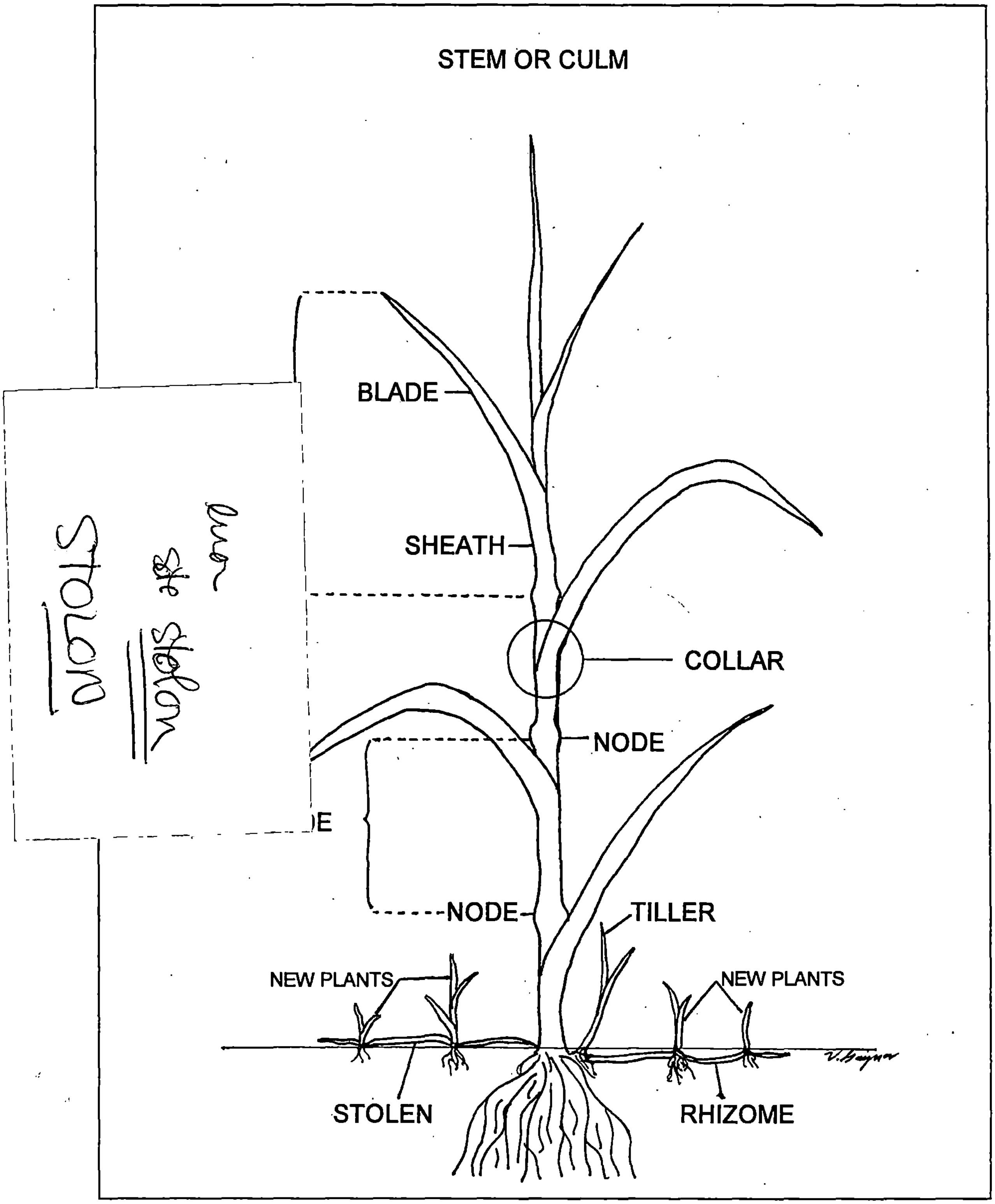

Figure 3-2. Collar of grass plant showing ligule and auricle.

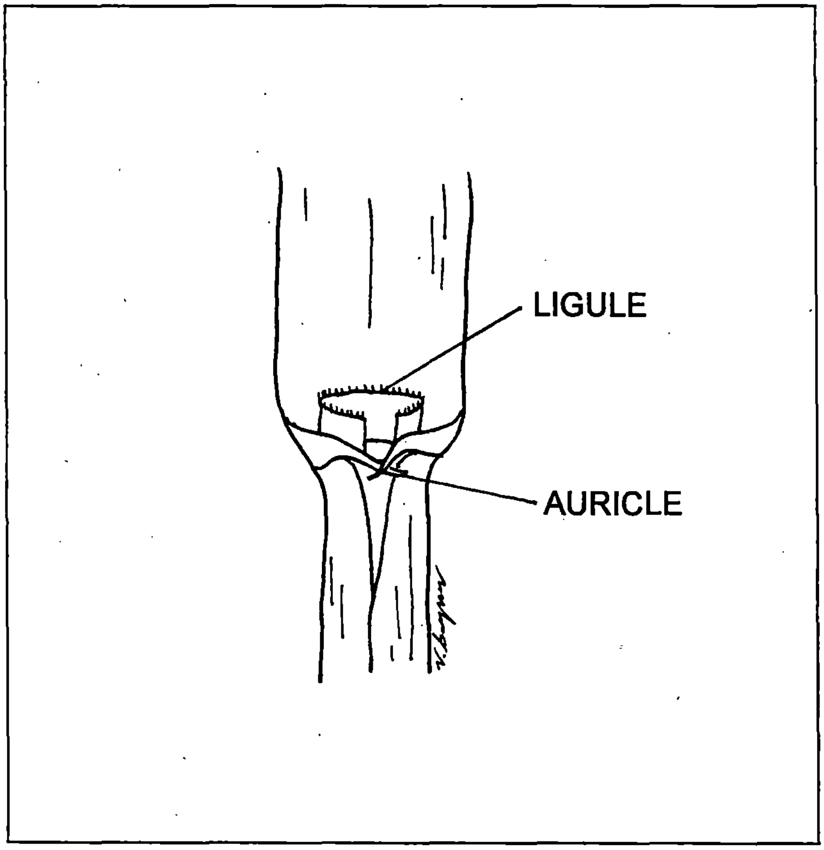

Figure 3-3. *Elymus canadensis*, collar of seedling leaf. Identifying characteristics include the claw-like clasping auricles and hairs along one margin of one sheath.

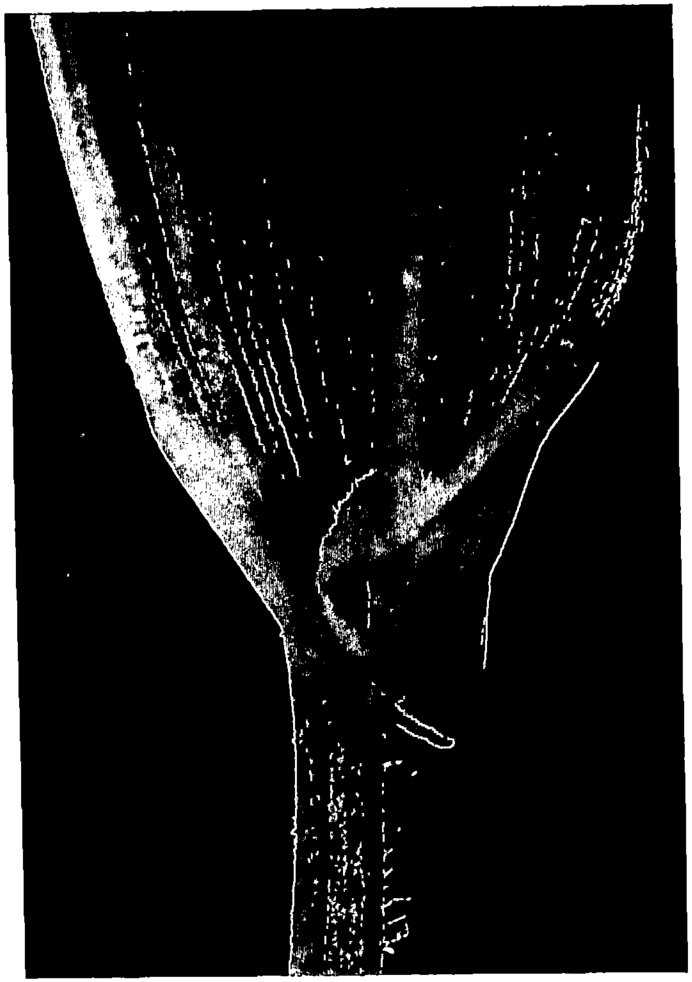

Figure 3-4. *Andropogon gerardii*, collar of seedling leaf. Identifying characteristics include lack of auricles, membranous ligule, pustules with a single hair along margin of leaf.

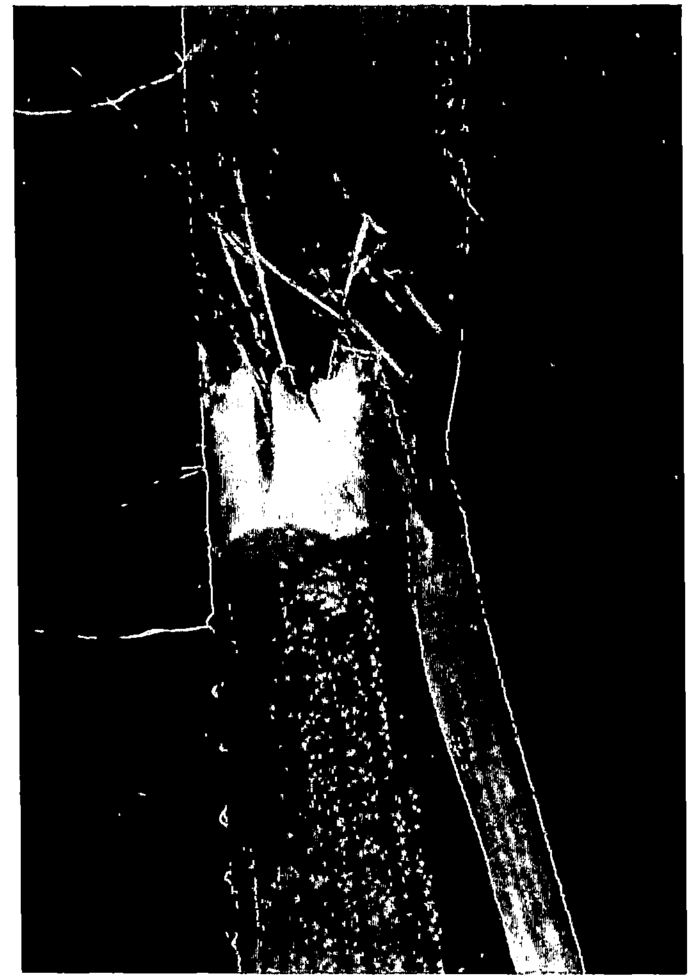

Figure 3-5. *Setaria viridis*, seedling. The leaf is rolled in the bud.

Figure 3-6. *Schizachyrium scoparium*, seedling leaf. The leaf is folded in half in the bud, with the margins of the leaf blade touching each other.

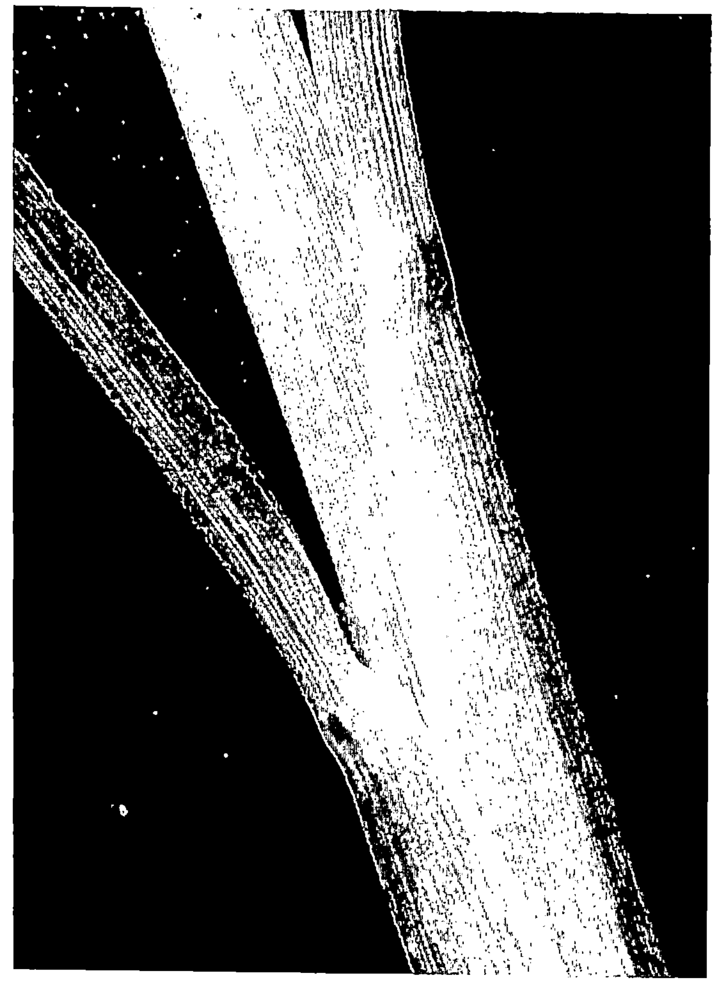

Figure 3-7. *Schizachyrium scoparium*, seedling. Culms are flat at the base of the plant and on young seedlings may fan out in a plane.

Figure 3-8. *Echinochloa crusgalli*, collar of seedling leaf. This is one of the few grass species with no ligule.

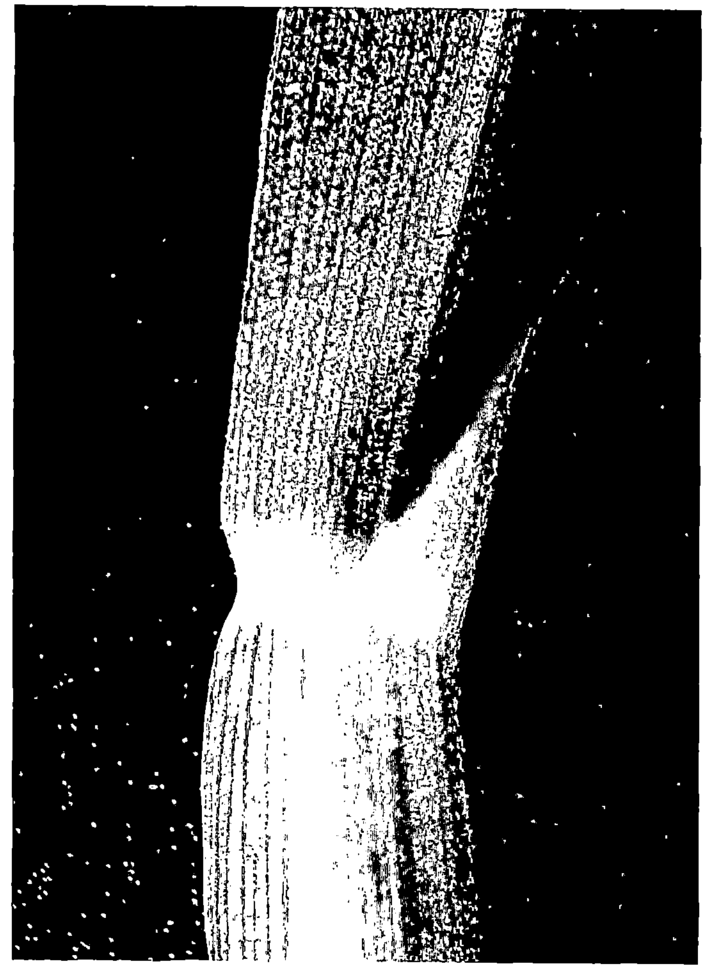

Figure 3-9. *Sorghastrum nutans*, collar of seedling leaf. The ligule in this species is a stiff membrane and is often described as a "rifle-sight".

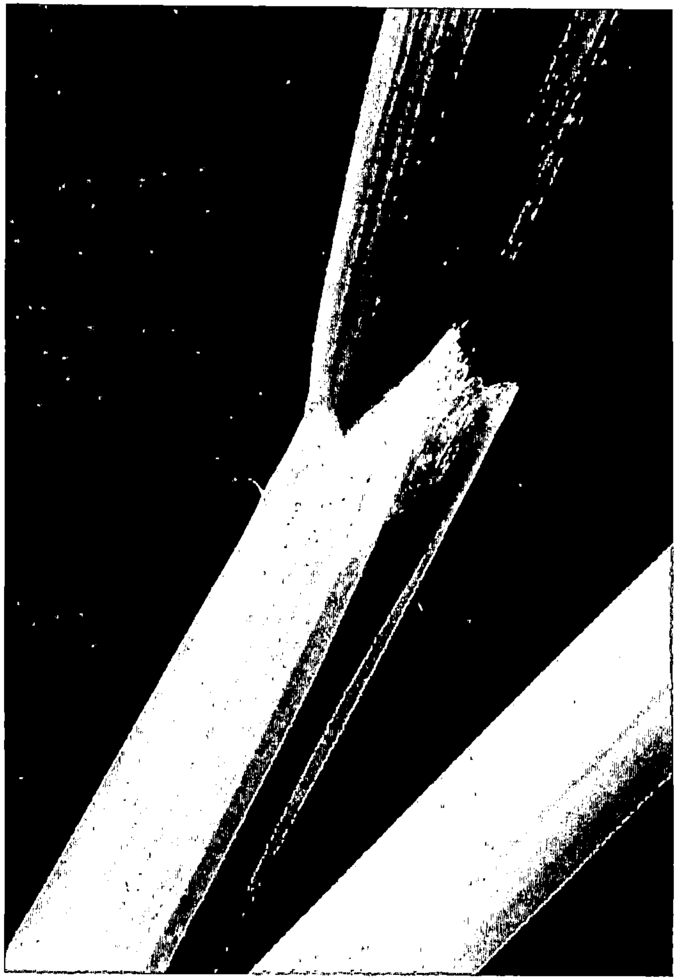

Figure 3-10. *Panicum vigatum*, collar of seedling leaf. The ligule consists of long hairs and the area above the ligule is very hairy.

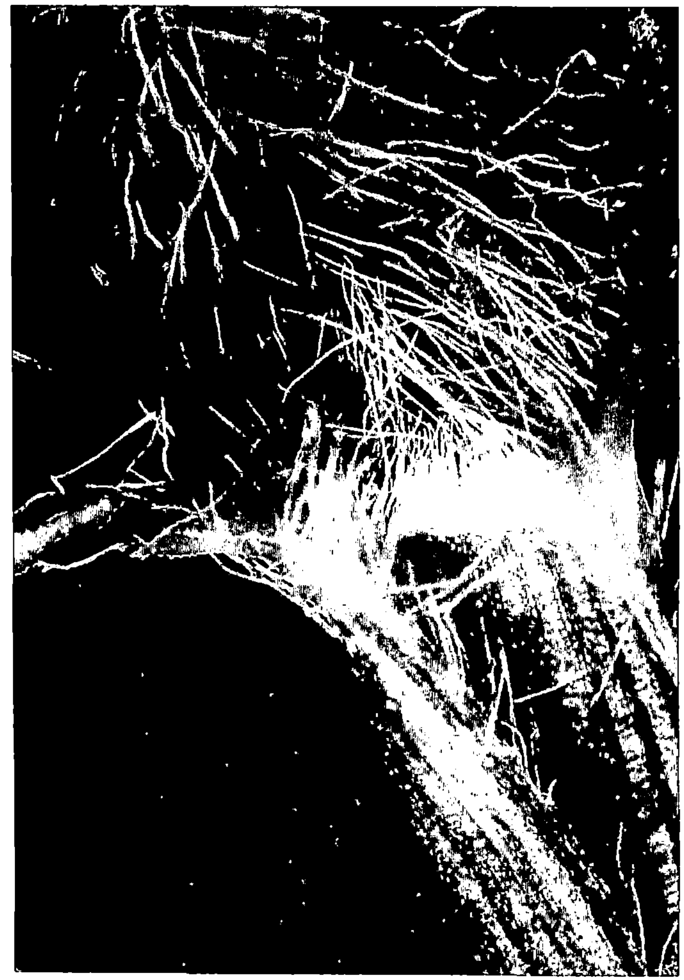

Figure 3-11. *Bouteloua curtipendula*, section of seedling leaf blade. Pustules are spaced along the leaf blade margins, with a single hair protruding from each pustule.

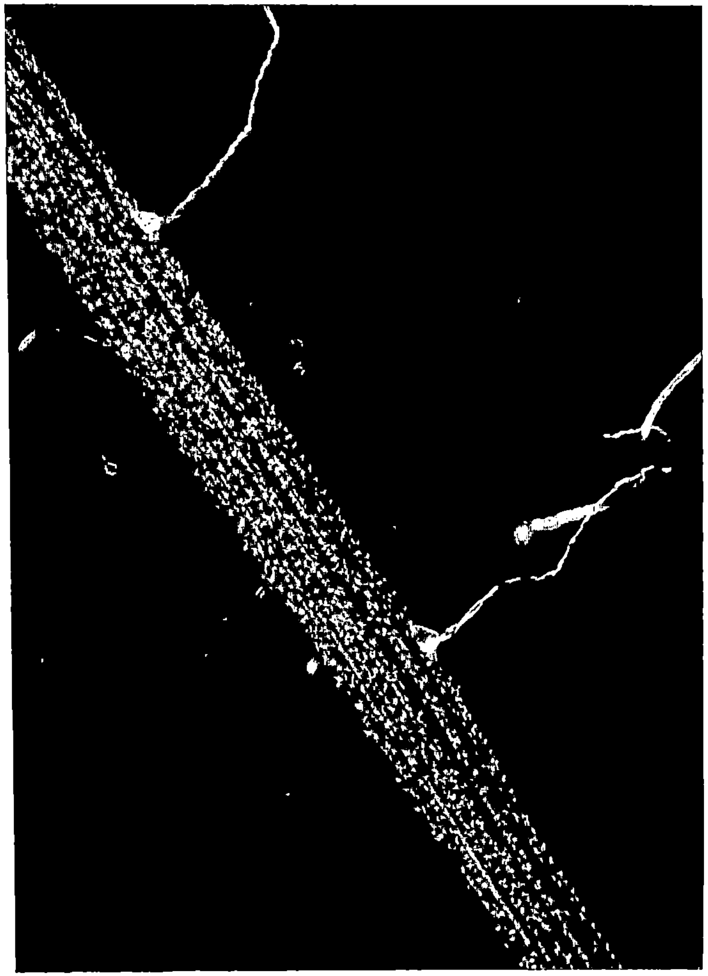

Figure 3-12. *Poa pratensis*, seedling. Photograph shows one lateral rhizome (left) and two upright culms (center and right).

Figure 3-13. Seedling Identification Key for eight native prairie grasses and seven non-native grasses.

Identification Key for Grass Seedlings

8 Native Prairie Grasses and 7 Common Non-native Grasses

1	**Claw-like auricles present on at least some leaves**	**2**
2	Hairs present along sheath margin	***Elymus canadensis***
2	No hairs along sheath margin	**3**
3	Auricles prominent; forms sod; long white or yellow rhizomes on older plants	***Elytrigia repens***
3	Auricles sometimes rudimentary; bunch form; long rhizomes not present	***Elymus trachycaulus***
1	**Claw-like auricles not present**	**4**
4	**Sheaths are flattened, not cylindrical**	**5**
5	New leaves folded in half lengthwise	**6**
6	Culms bright green	***Poa pratensis***
6	Base of culms often tinged pink or maroon; first tillers often fan out from crown in a plane	***Schizachyrium scoparium***
5	New leaves not folded in half, they are rolled	**7**
7	Ligule absent	***Echinochloa crusgalli***
7	Ligule present	**8**
8	Leaf blade wide (width:length ratio often 1:10 to 1:15)	***Digitaria sanguinalis***
8	Leaf blade long and narrow	***Andropogon gerardii***
4	**Sheaths cylindrical, not flattened**	**9**
9	Margin of leaf blade has long hairs protruding from pustules	**10**
10	Leaf blade wide (width:length ratio often 1:10 to 1:15)	***Panicum capillare***
10	Leaf blade long and narrow	**11**
11	Plant dark green; leaves very narrow	***Bouteloua curtipendula***
11	Plant medium green or blue green	***Andropogon gerardii***
9	Margin of leaf blade without pustules	**12**
12	Ligule consists of long hairs	**13**
13	Sheath hairy	***Panicum capillare***
13	Sheath not hairy	**14**
14	Leaf blade wide (width:length ratio often 1:10 to 1:15)	***Setaria viridis***
14	Leaf blade long and narrow	***Panicum virgatum***
12	Ligule consists of membrane (may be fringed with short hairs)	**15**
15	Sheath is tubular	**16**
16	Both sheath and blades with many fine hairs	***Bromus kalmii***
16	Sheath with fine hairs; blade appears smooth	***Bromus inermis***
15	Sheath not tubular, it is open or has overlapping margins	**17**
17	Leaf blade wide (width:length ratio often 1:10 to 1:15)	***Digitaria sanguinalis***
17	Leaf blade long and narrow	**18**
18	Claw-like or rudimentary auricles	***Elymus trachycaulus***
18	No claw-like auricle; ligule tall and stiff	***Sorghastrum nutans***

Figure 3-14. Field Guide to Seedling Identification of eight native and seven non-native grasses, Part A.

VEGETATIVE GUIDE TO SELECTED GRASSES

1. **Are claw-like auricles present? → GO TO A**
2. **If not, are stems flattened? → GO TO B**
3. **If not, are stems cylindrical? → GO TO C**

DESCRIPTION OF TRAITS

Auricles	Clasping claw-like auricles are present. They should be easily visible with naked eye. Check several leaves since some may be without auricles.
Flat or cylindrical?	Are stems and sheaths flat or cylindrical? A cylindrical sheath should twirl smoothly between thumb and third finger.
Folded or rolled?	Newly emerging leaves will be folded in half within the sheath or they will be rolled in the sheath. Look at the lengthwise edge of the leaf blade to determine if the shoots are folded or rolled.
Pustules	Some plants have pustules along the margin of the leaf blade. Protruding from each pustule is a long hair. Pustules and hairs are visible to the naked eye if lighting is adequate.
Ligule	The ligule may be a membrane, long hairs, or a membrane with hairs. A few grass species have no ligule.
Sheath	Below the collar, the sheath may be open, have overlapping margins, or it may be a closed tube (tubular).
Leaf width	Leaf width described by the width:length ratio of the leaf blade. A leaf that is 1 cm. wide and 10 cm long would be 1:10. Wide leaves -- 1:5, 1:10, 1:15; narrow leaves -- 1:20, 1:25, 1:30, etc.

A. CLAW-LIKE AURICLES PRESENT

A. Hairs on sheath margin .... ***Elymus canadensis***

B. No hairs on sheath margin
- 1) Auricles prominent; sod forming; long white or yellow rhizomes on older plants .... ***Elytrigia repens***
- 2) Auricles sometimes rudimentary; bunch form; long rhizomes not present .... ***Elymus trachycaulus***

B. NO CLAW-LIKE AURICLES, STEMS ARE

A. New leaves folded in half lengthwise
- 1) Culms bright green .... ***Poa pratensis***
- 2) Base of culms often tinged pink or maroon .... ***Schizachyrium scoparium***

B. New leaves not folded, rolled
- 1) Ligule absent .... ***Echinochloa crusgalli***
- 2) Ligule present
  - a) Leaf blade wide .... ***Digitaria sanguinalis***
  - b) Leaf blade long and narrow .... ***Andropogon gerardii***

C. NO CLAW-LIKE AURICLES, STEMS ARE CYLINDRICAL

A. Leaf blade margin has pustules with long hairs
- 1) Leaf blade wide .... ***Panicum capillare***
- 2) Leaf blade long and narrow
  - a) Plant dark green; leaves very narrow .... ***Bouteloua curtipendula***
  - b) Plant medium green or blue green .... ***Andropogon gerardii***

B. Leaf blade margin without pustules
- 1) Ligule consists of long hairs
  - a) Sheath hairy .... ***Panicum capillare***
  - b) Sheath not hairy
    - i) Leaf blade wide .... ***Setaria viridis***
    - ii) Leaf blade long and narrow .... ***Panicum virgatum***
- 2) Ligule consists of membrane
  - a) Sheath tubular
    - i) Sheath and blade with many fine hairs .... ***Bromus kalmii***
    - ii) Sheath with fine hairs, blade smooth .... ***Bromus inermis***
  - b) Sheath not tubular
    - i) Leaf blade wide .... ***Digitaria sanguinalis***
    - ii) Leaf blade long and narrow
      - a) Claw-like or rudimentary auricles .... ***Elymus trachycaulus***
      - b) No claw-like auricle, tall stiff ligule .... ***Sorghastrum nutans***

Figure 3-15. Field Guide to Seedling Identification of eight native and seven non-native grasses, Part B.

KEY FEATURES OF SPECIES

Native Grasses

Andropogon gerardii **- big bluestem**
- Shoot rolled in bud (but may be creased)
- Long hairs protrude from small pustules spaced along lower portion of leaf blade (not as distinct as *B. curtipendula*)
- Stems cylindrical or flattened
- Ligule - membrane

Bouteloua curtipendula **- sideoats grama**
- Long hairs protrude from pustules spaced along lower portion of leaf blade margin
- Stems cylindrical
- Shoot rolled in bud
- Dark green color
- Ligule - membrane with short hairs

Bromus kalmii **- Kalm's brome**
- Very young seedling often olive green
- Stems cylindrical or flattened, shoot rolled in bud
- Very soft fine hairs, often feels silky
- Ligule - short membrane, base often arches in inverted V
- Tufted, tillers grow in cluster unlike *B. inermis*
- Upper sheath is tubular

Elymus canadensis **- Canada wildrye**
- Claw-like clasping auricles
- One margin of sheath has hairs
- Stems cylindrical, shoot rolled in bud
- Ligule - membrane

Elymus trachycaulus **- slender wheatgrass**
- Claw-like clasping auricles or rudimentary or absent
- Stems cylindrical, shoot rolled in bud
- Ligule - membrane
- Tufted form, may have short rhizomes

Panicum virgatum **- switchgrass**
- Stems cylindrical, shoot rolled in bud
- Older culms may have thick patch of hair above ligule otherwise blades generally without hairs
- Ligule - fringe of long hairs fused at base

Schizachyrium scoparium **- little bluestem**
- Stems flattened, shoot folded in half in bud
- Base of stems generally pink or maroon
- Ligule - membrane; front edges pull collar shut
- On young plant new tillers often fan out in a plane

Sorghastrum nutans **- Indian grass**
- Stems cylindrical, shoot rolled in bud
- Ligule - tall stiff membrane, may be notched on older stems
- Ligule margin often appears to be part of sheath margin

Non-native Grasses

Bromus inermis **- smooth brome**
- Stems cylindrical, shoot rolled in bud
- Soft fine hairs, fewer hairs than *B. kalmii*
- Tillers grow out away from first stem, unlike *B. kalmii*
- Ligule - short membrane, base often arches in inverted V
- Auricles usually absent, sometimes rudimentary
- Upper sheath is tubular

Digitaria sanguinalis **- crab grass**
- Stems flattened (may appear cylindrical), shoot rolled in bud
- Leaf blades wide
- Ligule - membrane
- Internodes not covered by sheath on older stems

Echinochloa crusgalli **- barnyard grass**
- Stems flattened, but thick and wide
- Shoot rolled in bud
- Ligule absent
- Leaves and stems without hairs

Elytrigia repens **- quack grass**
- Claw-like clasping auricles
- Long white or yellow rhizomes on older plants
- Stems cylindrical, shoot rolled in bud
- Ligule - membrane
- Lower sheaths usually with hairs, blades usually without

Poa pratensis **- Kentucky bluegrass**
- Stems flattened
- Shoot folded in half in bud
- Rhizomes
- Bright green or lime green color

Panicum capillare **- witch grass**
- Stems cylindrical, shoot rolled in bud
- Ligule - long hairs fused at base
- Sheaths and blades hairy, sheath margin not hairy
- Leaf blades often wide, blades widest at base
- Long hairs protrude from small pustules spaced along lower portion of leaf blade (not as distinct as *B. curtipendula*)

Setaria viridis **- green foxtail**
- Stems cylindrical, shoot rolled in bud
- Leaf blades wide, leaf blade widest at middle
- Ligule - long hairs fused at base
- Hairs at collar margin
- One margin of sheath has hairs

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